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Detection and characterization of defects in moving parts of wind turbines

E Forero¹ D Tibađuiza¹ M Anaya¹ R Castro¹

¹ Facultad de Ingeniería Electrónica, Universidad Santo Tomás –Colombia, Bogotá

E-mail: {edwinforero , diegotibađuiza, maribelanaya, rafaelcastro }@usantotomas.edu.co

Abstract. The detection, localization and characterization of defects in a material or a part that conform a structure is possible by using the transmission and reception of ultrasonic signals. Different strategies are used to achieve extract information from the part under evaluation. For this, it is then possible to use a distributed sensors arrays on the surface of the material and using scanning techniques such as are A-scan or B-scan, where it is possible to increase the level of detail regarding location, orientation and size of defects found, according to the strategy used. However, the systems and inspection techniques are often limited by the geometries and access to different types of structures. Due to these reasons, the acquisition of the returned signals, for identification and attenuation time, can suppress valuable information for accurate characterization of imperfections found in shape and location. In this paper, the use of spectral analysis of the collected signals is proposed as a tool for detection and characterization of defects in a structure. This analysis allows to determining the power distribution in a frequency range. This methodology is useful in non-destructive evaluation when it is not possible to have full access to the structure under inspection. In this case it is applied on a wind turbine operating to make the study of different echoes captured according to the geometry of the part and comparing said conducting analysis with previously established patterns of shapes, orientations, and sizes of defects found.

Introduction

Inspection of materials and component parts of structures allow a reliable criterion in certifying their quality. The inspection process is performed by capturing data using different techniques; for instance, the emission and reception of waves over the structure by piezoelectric active sensors [1], and Fiber Bragg Gratings using lamb waves [2], [3]. The piezoelectric technique is performed with transducers whose resonant frequencies are between the orders of kHz. Also is important to perform suitable signal capturing by the acquisition system, and this process involves the develop of specific data treatment modules for subsequent use of different signal processing techniques in order to identify the existence and nature of the found defects, so the work of the inspector provided along with methodologies attempt to find adequate precision.

¹ edwinforero@usantotomas.edu.co



In this work operation frequency spectral analysis is presented as in [4] and [5] to distinguish defects in the surface of a material, but with some changes such as data organization, pre-processing and data analysis. The methodology is tested using damages which are produced over the aluminium alloy structure, so the technique is destructive due to characterize the real damage nature and relational behaviour at the frequency spectral domain. This paper continues with a description of the experiment, then a frequency analysis is presented and finally the conclusions of the work are written.

Physical Principle

In solid materials, molecules can be forced to vibrate in different amplitudes and frequencies by applying diverse kinds of sound waves at any direction. The interaction between these mechanical waves and moving surfaces allow to extract information of damages and defects. Waves traveling on such surfaces are called lamb waves, they are generated by a piezoelectric transducer added to the surface under study. Lamb waves can vibrate in different modes, but the most common are asymmetric or symmetric, in this sense, the wave frequency characteristic can be an indication of the changes in the structures such as different damage shapes and surface boundaries.

Description of the experiment

For the experimental setup, an aluminium alloy structure was instrumented with two piezoelectric sensors attached permanently to the extremes of one of its faces (figure 1a). Both piezoelectrics, act as actuator/sensors in different actuation phases of the experiment, this configuration is used to apply the input and for the acquisition of the signals [13]. The input signals are generated by means of a burst signal with 8V of amplitude (figure 1b). The data are collected with an HS4 TiePie oscilloscope at a 2 MHz sample rate, and organized by actuation phases as in Tibaduiza 2013 [5]. The input signal generation and acquisition program were developed in MATLAB.

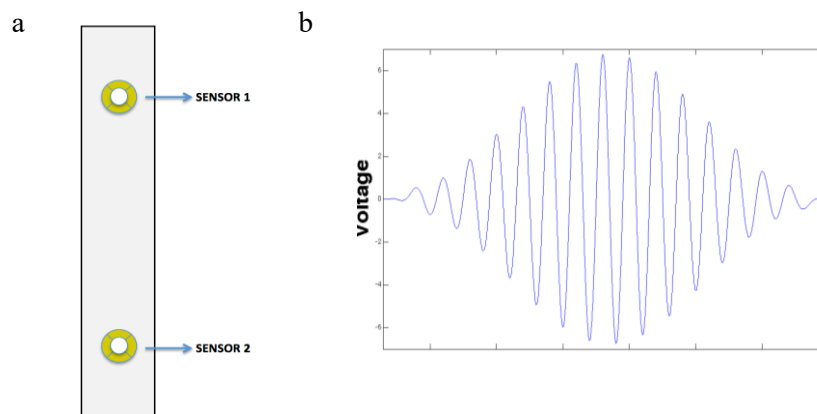


Figure 1. a) Shows the arrangement of piezoelectric transducers permanently attached to the aluminum structure on one of its faces.
b) input signal, burst 10 kHz in hamming window

To carry out the work, six different damages were applied to the structure. The damages included are: one surface circular damage with 3.5mm radius (figure 2b), one round hole with 4.7 radius (figure 2c), one round hole with 6.2 radius (figure 2d), one equilateral triangle hole with 12mm of side (figure 2e), one right trapezoidal hole with base and side of 12mm (figure 2f) and one square hole 12mm side (figure 2g).

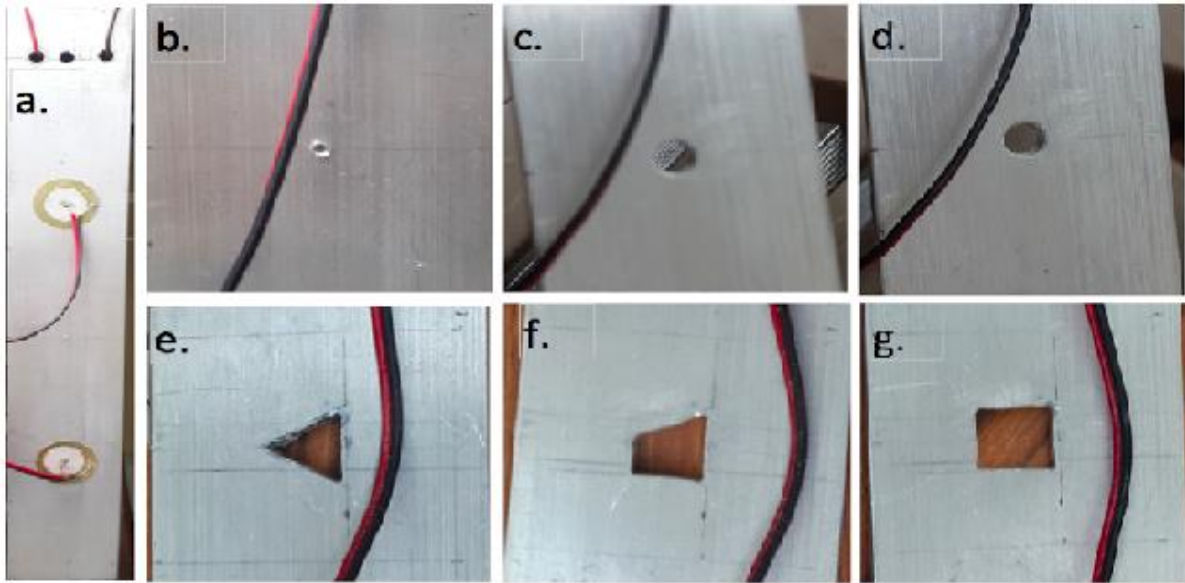


Figure 2. a) Healthy structure. The evaluated defects: b) Surface circular, c) round hole with 4.7 radius. d) Round hole with 6.2 radius. e) Equilateral triangle. f) Right trapezoidal. And g) Square hole.

In the acquisition process there were performed in total one hundred forty measurements related to twenty data obtained for each one of the six different geometries and twenty for the undamaged case. The type of acquired signals are shown in figure 3.

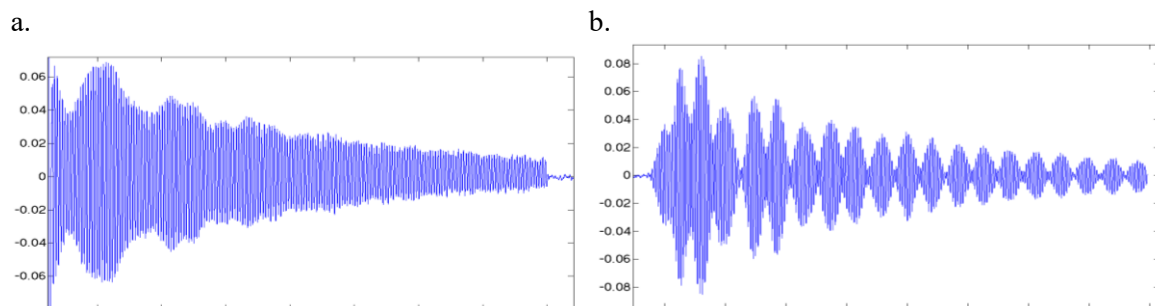


Figure 3. The acquired data: a) Return wave for the actuation sensor. b) Wave of signal by the received sensor.

For all the damaged cases, the data were evaluated in the frequency domain considering each actuation phase in order to obtain the central frequency.

Frequency Analysis

The acquired data were organized in a new dataset containing all data from the undamaged and damaged structure, after the Discrete Fourier Transform (DFT) is applied. For all the damage cases the

data were evaluated in the frequency domain and the results (power by phase [dB]) are included in the Figure 4.

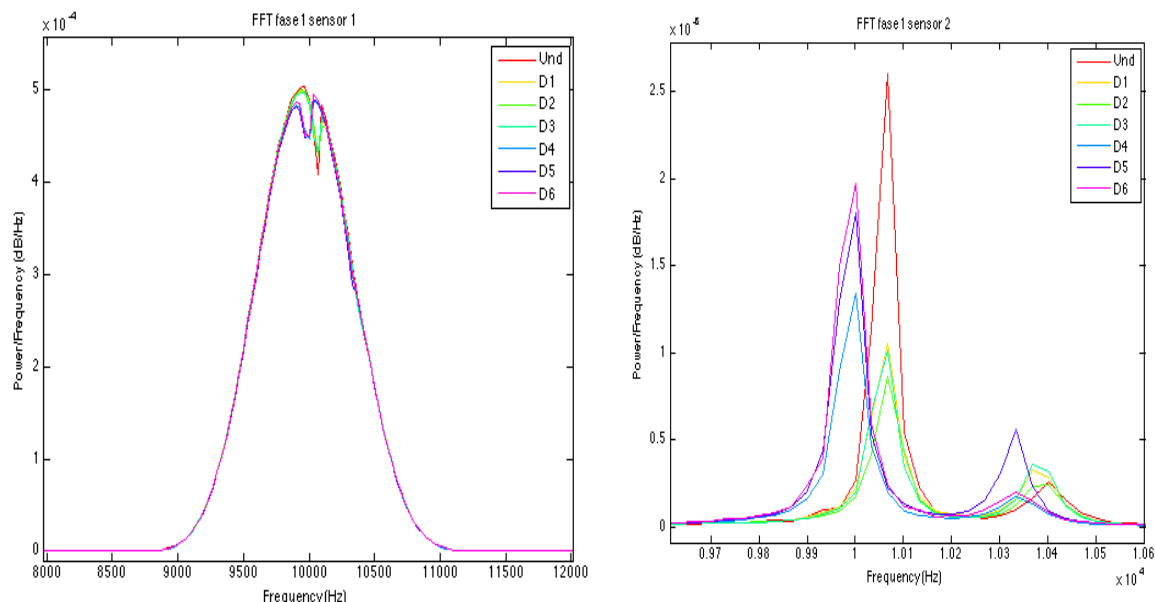


Figure 4. Figure with short caption (caption centred) of the healthy structure and the evaluated defects central frequency power for the phase 1; sensor 1 actuation and sensor 2 reception; D1- Undamaged structure. D1-Surface circular damage with 3.5mm radius. D2- Round hole with 4.7 radius. D3-Round hole with 6.2 radius. D4-Equilateral triangle hole with 12mm of side. D5- Right trapezoidal hole with base and side of 12mm. D6-Square hole 12mm side.

The obtained results (Figure 4) in the frequency domain show an important feature, this is the emergence of new frequency components, frequencies rounding the 10 KHz with different amplitudes in the spectrum, which will be evident in the defects distinction. In the actuating sensor, damages related to the equilateral triangle, the right trapezoidal and the square holes, shows in the spectrum different shape than for the round surface and holes damages, these lasts are more close in shape for the undamaged case, a relate behavior is observed for the receiving sensor spectrum, but in this case there is a shift of the frequency bands, showing a very different central frequency between round damages and the others. For the actuating spectrum, the main phenomena related to the frequency is the return wave, so it can be said that round damages produce a change in the magnitude but not in frequency responses. For the receiving sensor this change of central frequency is mainly related to the shape of the damage, the circular defects seem to be closer in frequency to the data from the undamaged structure presenting only differences in the magnitude, while the planar face damages have a central frequency component which is below the undamaged state, in the same way, there are different magnitudes. A graphic analysis of the responses in the frequency domain obtained by the discrete Fourier transform (DFT) for each of the events evaluated is shown in the table 1 and the magnitudes in the central frequencies for each case are included in the table 2.

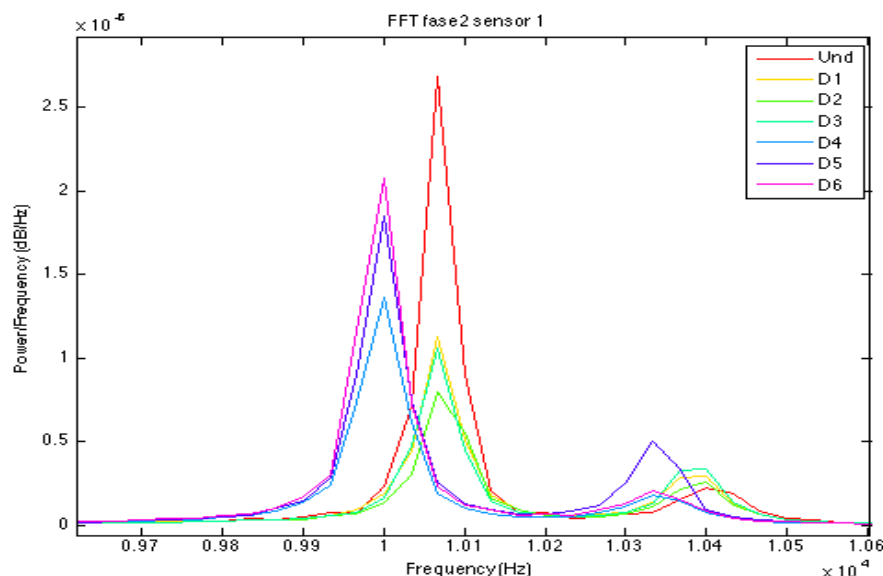


Figure 5. Figure with short caption (caption centred) of the healthy structure and the evaluated defects central frequency power: D1- Undamaged structure. D1-Surface circular damage with 3.5mm radius. D2- Round hole with 4.7 radius. D3-Round hole with 6.2 radius. D4-Equilateral triangle hole with 12mm of side. D5- Right trapezoidal hole with base and side of 12mm. D6-Square hole 12mm side.

A result from the previous plot (Figure 5), is that for the planar-faced damages, the central frequency magnitude in the receiving sensor seems to be increased with the damage size. In the same way there are some shifts in the central frequency and the amplitude by each actuation phase.

Table 1. Central frequency (Hz).

	Central frequency(Hz)			
	phase 1		phase 2	
	Sensor 1	Sensor 2	Sensor 1	Sensor2
Undamaged	10000,167	10067,058	10000,167	10033,612
Superficial and circular, radius 3,5 mm	9966,7217	10067,058	10100,503	9966,7217
Circular, radius 4,7 mm	9966,7217	10067,058	10100,503	9966,7217
Circular, radius 6,2 mm	9966,7217	10067,058	10100,503	9966,7217
Equilateral triangle, side 12mm	10067,058	10000,167	10033,612	9966,7217
Square, side 12 mm	10067,058	10000,167	10033,612	9966,7217
Right trapezoid, base and side 12mm	10067,058	10000,167	10033,612	9966,7217

Table 2. Power in the central Frequency (dB).

	<i>Power in the central Frequency (dB)</i>			
	<i>phase 1</i>		<i>phase 2</i>	
	<i>Sensor 1</i>	<i>Sensor 2</i>	<i>Sensor 1</i>	<i>Sensor2</i>
Undamaged	0,000503073	0,000494021	1,9677968E-06	2,0702139E-06
Superficial and circular, radius 3,5 mm	0,000497978	1,0590177E-06	1,1297371E-06	0,000518213
Circular, radius 4,7 mm	0,000496072	1,0113313E-06	1,0584284E-06	0,000517697
Circular, radius 6,2 mm	0,000499121	8,6029257E-07	7,9817715E-07	0,000518741
Equilateral triangle, side 12mm	0,000486173	1,3389920E-06	1,3606202E-06	0,000509451
Right trapezoid, base and side 12mm	0,000494021	1,9677968E-06	2,0702139E-06	0,00051361
Square, side 12 mm	0,000488466	1,8030465E-06	1,8498930E-06	0,000513379

Conclusions

The methodology herein presented, which is based on a piezoelectric transducer approach makes use of transducers which are working as sensor and actuators working in different actuation phases provides a good system to produce mechanical waves over materials. From the information acquired by frequency analysis we can see that both the receiving and the actuation sensor data provides a good differentiation between planar-faced damages and round damages with little shift over the frequency band. Round damages presented magnitude changes while conserving frequency similarities, finally in the case of the planar-faced damages, frequency changes and magnitude proportional to damage size were obtained.

Acknowledgments

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